A 60-Sat Space Weather Constellation with Real-Time, 24/7, Globalstar Link

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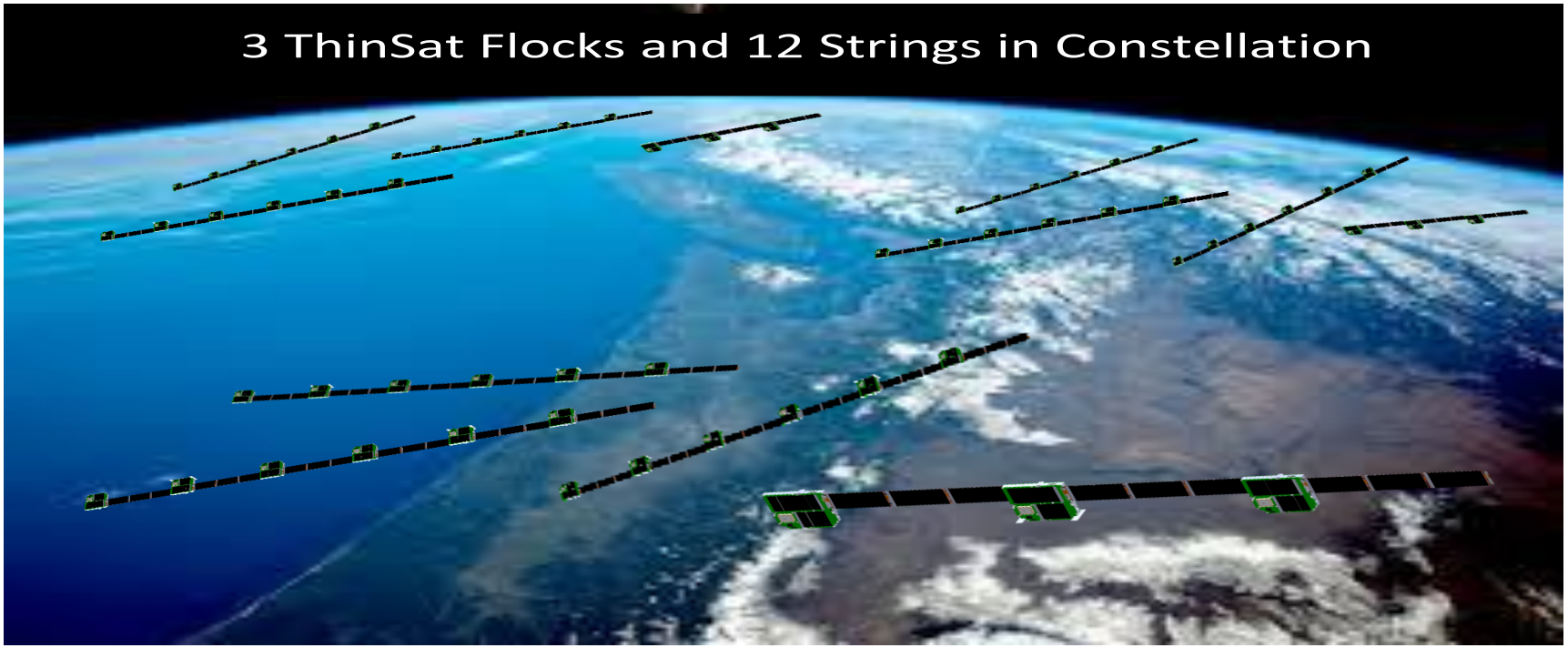
History---Challenge---SW Data---G*---ThinSats----Flock----Ground Seg.----Next---?

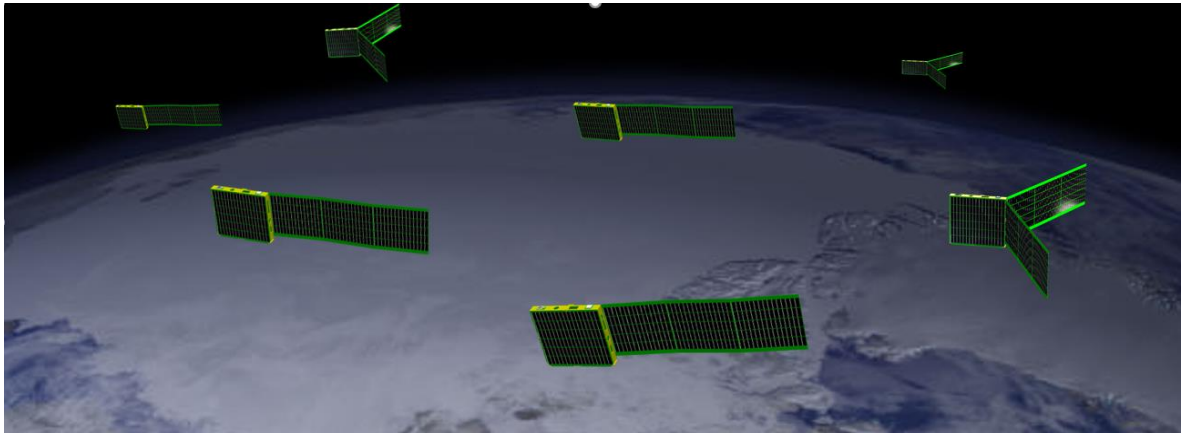
SW: Satellite, Radios, Data Analysis, & Balloons

Multi-Point and Instant data on Internet

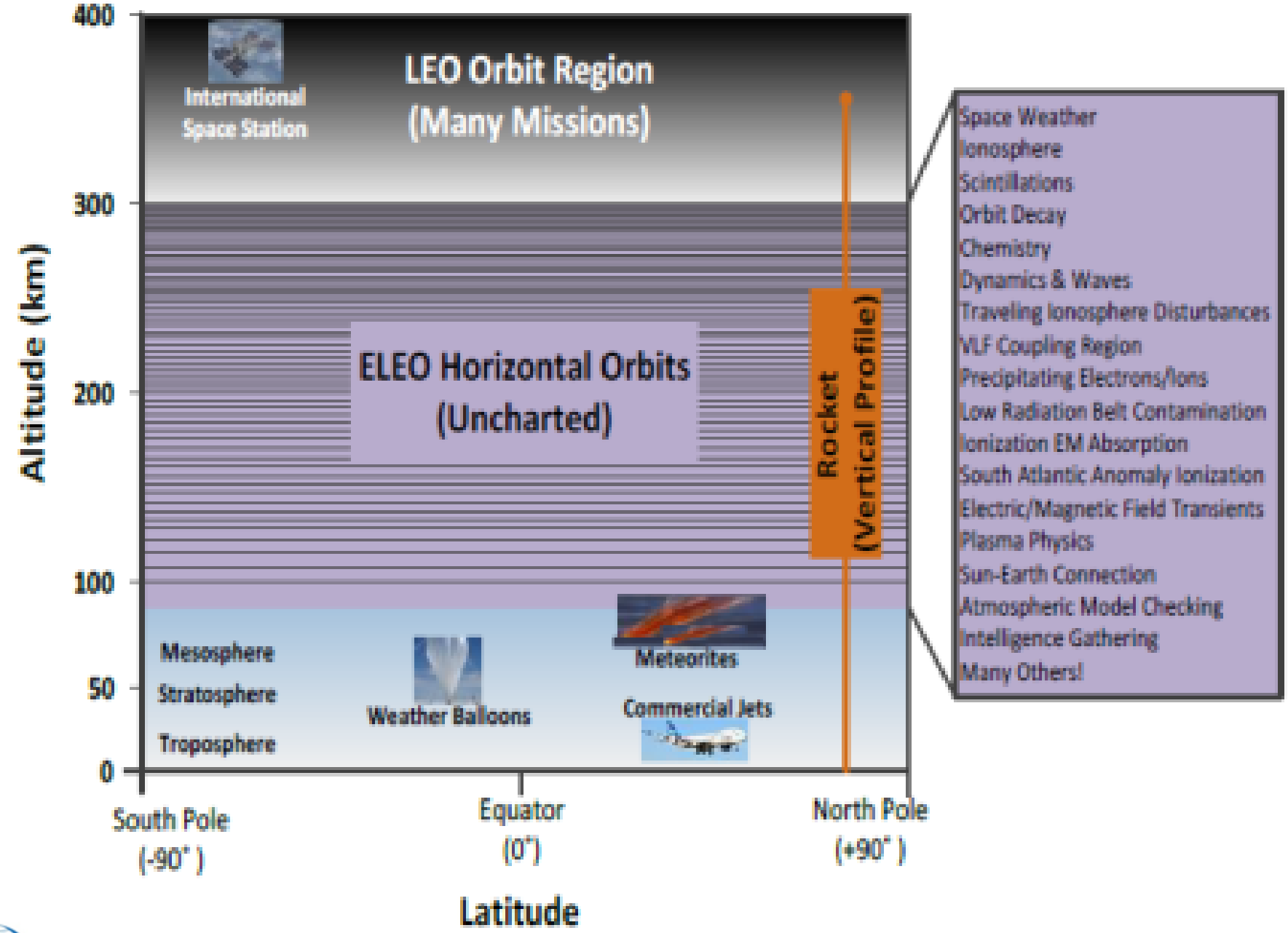


Current ThinSats 1U by 1U by 1/7 U or ~11 by 11 by 7 cm

Above Demonstration ThinSat Launch in two weeks, April 17, 2019 from Wallops Island, VA on NG11 resupply ISS mission. Three 3U CSD containers.



ThinSats are scalable 3U by 3U by ½ U, 6 in one 27U CSD


400
300
200
100
50
0
Altitude (km)
International Space Station
LEO Orbit Region (Many Missions)
ELEO Horizontal Orbits (Uncharted)
Rocket (Vertical Profile)
Mesosphere
Stratosphere
Troposphere
Weather Balloons
Meteorites
Commercial Jets
Space Weather
Ionosphere
Scintillations
Orbit Decay
Chemistry
Dynamics & Waves
Traveling Ionosphere Disturbances
VLF Coupling Region
Precipitating Electrons/Ions
Low Radiation Belt Contamination
Ionization EM Absorption
South Atlantic Anomaly Ionization
Electric/Magnetic Field Transients
Plasma Physics
Sun-Earth Connection
Atmospheric Model Checking
Intelligence Gathering
Many Others!
South Pole (-90°)
Equator (0°)
North Pole (+90°)
Latitude

VLEO 170-230 km 1982 S81-1 Corona (Rich for Discovery & Forecasting SW Data Sets)

- Voss, H. D., et. al, *J. Geophys. Res.*, 103, 11,725-11,744, 1998

- Voss, H. D., Lightning-Induced Electron Precipitation, *Nature, 312*, 740, 1984

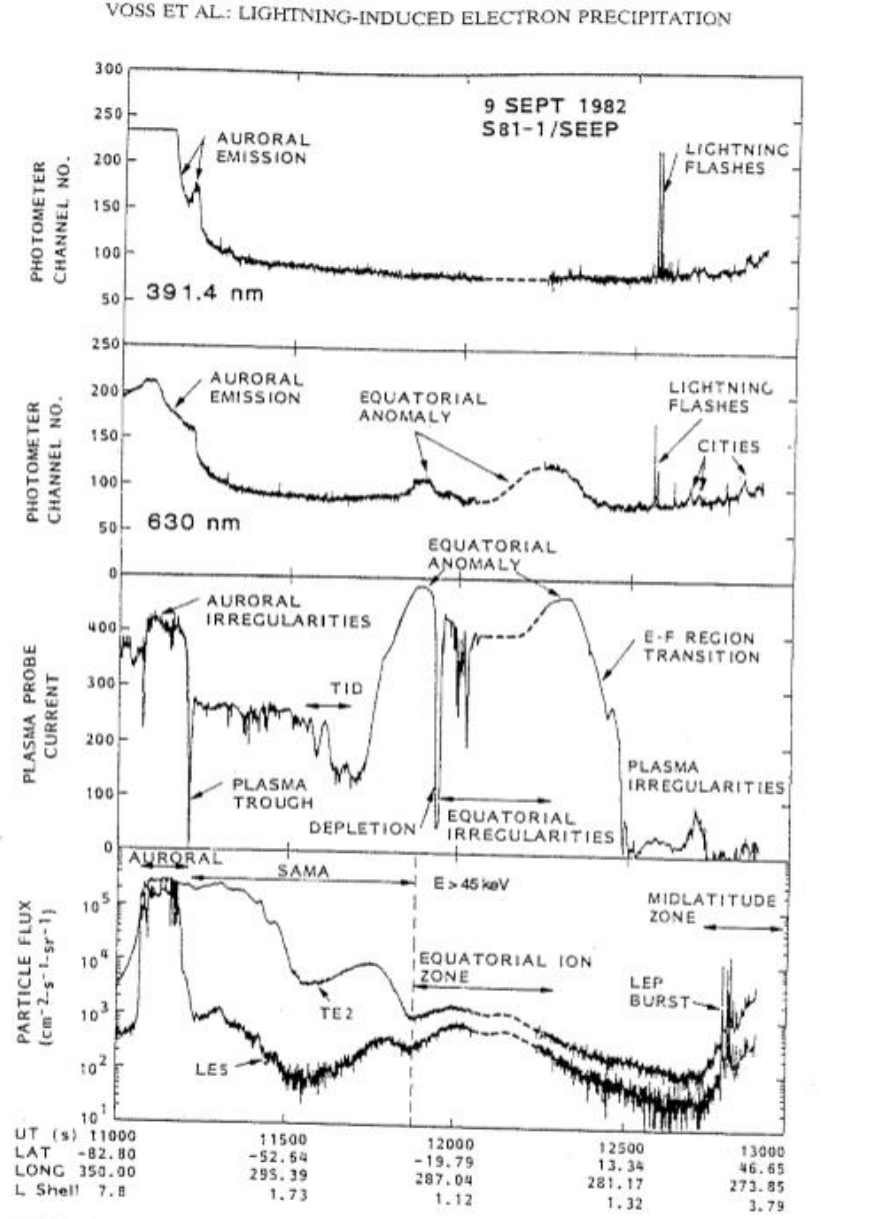


Figure 3. SEEP detector response during a nighttime pass September 9, 1982. Top two panels are photometer data at 391.4 and 630 nm; the third panel is the plasma probe response. The bottom panel shows the particle flux intensities for the TE2 (trapped) and LE5 (precipitating) electron sensors.

VLEO or ELEO Region (90 to 350km): ThinSats for Research, DOD, Space Weather, and Education

- **Science:** Underexplored region of space that is very important for Atmosphere Climate coupling, **Space Weather**, Global Electric Circuit, E-F region, In situ Ionosphere, Precipitating energetic particles, gravity waves, and much more! … see science papers
- **Technology:** Aerodynamic control, Reentry Physics, tethers, Intelligence gathering, remote sensing, ion thrusters, …
- **Little Space Debris Concern**: Lifetime weeks to months, Ideal for constellations, Much less Radiation Damage or Flare/EMP damage
- **Aerodynamic ThinSats:** for making unprecedented measurements with low cost satellites. for a instant monitoring of waves, plasma, particles, EM spectrum, constituents, and remote sensing.
- **Operational to Educational** space for many consecutive low cost missions… a **SANDBOX** for Rapid Innovation.

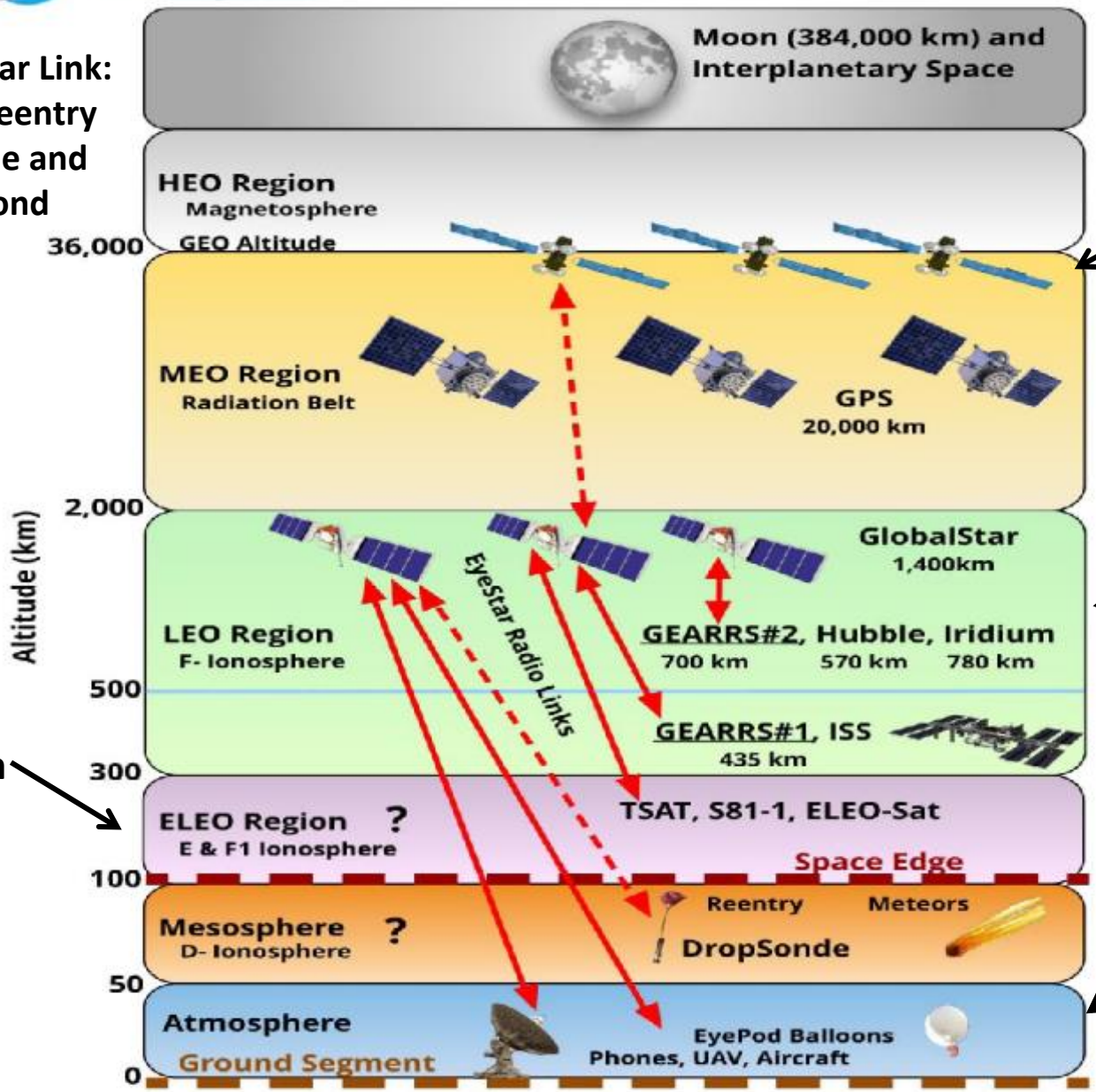
Space Weather Phase 1 Benchmarks
National Science & Technology Council

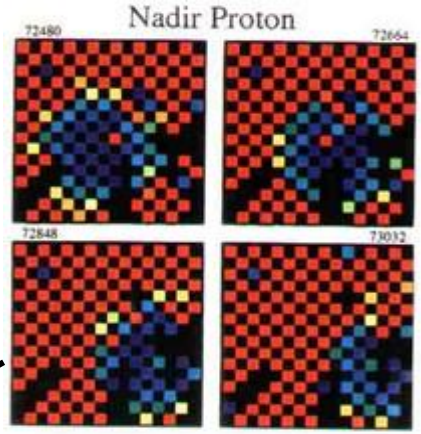
June 2018

Agencies, Departments, Executive Offices

- Benchmark: Induce Geo-Electric Fields
  - Less noise: ThinSat can fly E and B field sensors in VLEO.
- Benchmark: Ionizing Radiation
  - Less Background radiation! Direct precipitating energetic particle sensors in VLEO. Also monitor UV and X-ray ionization in Ionosphere.
- Benchmark: Ionospheric Disturbances
  - Direct in situ F-region densities, Temperatures, and Dynamics:
- Benchmark Upper Atmospheric Expansion
  - Direct in situ measurements of drag, plasma trough, auroral compression, and composition

Globalstar Link: From Reentry Altitude and Beyond





NASA POLAR SEPS

Globalstar
TSAT,
GEARRS1
GEARRS2
V/ELEO Region
Reentry Region
Dropsondes
MEO, GEO

ThinSat Program

400 High-Altitude Balloon Lunches

NSL/Globalstar EyeStar History Flights

2014

TSAT 2U

EyeStar Simplex
Space X Launch
ElaNa 5 325 km
40 day life
NSL and Taylor U

2015

GEARRS1 3U

EyeStar 2 Simplex
EyeStar Duplex
SMS Commanding
Orbital Launch, ISS
410 km, Bat. Life
DOD STP
Deployment Delay
Partial Mission Success

GEARRS2 3U 2015

EyeStar Simplex
EyeStar Duplex
SMS Commanding
Atlas Launch,
350X700 km, 1.5 yr.
DOD STP & NRO

2016

1U Polar Orbit, 6U ISS
6U

EyeStar Simplex
EyeStar Duplex
ISS Launch, ~420 km
DOD STP

2017-18 CubeSat: 7
EyeStar Radios: 27
NSL Systems: 60+
Manifast 2019: 75

NASA, AF,
Industry, Others,
25 units NSL Inventory

24/7 Data collection with latency of several seconds

Eyestar Simplex

Simplex: STX-3 (or STX-2): 200 Kbytes/day, 9 Bytes/sec

Low Power/cost/size , Turn-on data in seconds, 2KB/day, global Anywhere/Anytime data, Tumbling OK, processor validated
5 of 5 Validated in LEO Orbit!
3 week Available NSL Stock

Many Radios Sold to DOD, NASA, Industry, & Universities

Mission Success, No Ground station required

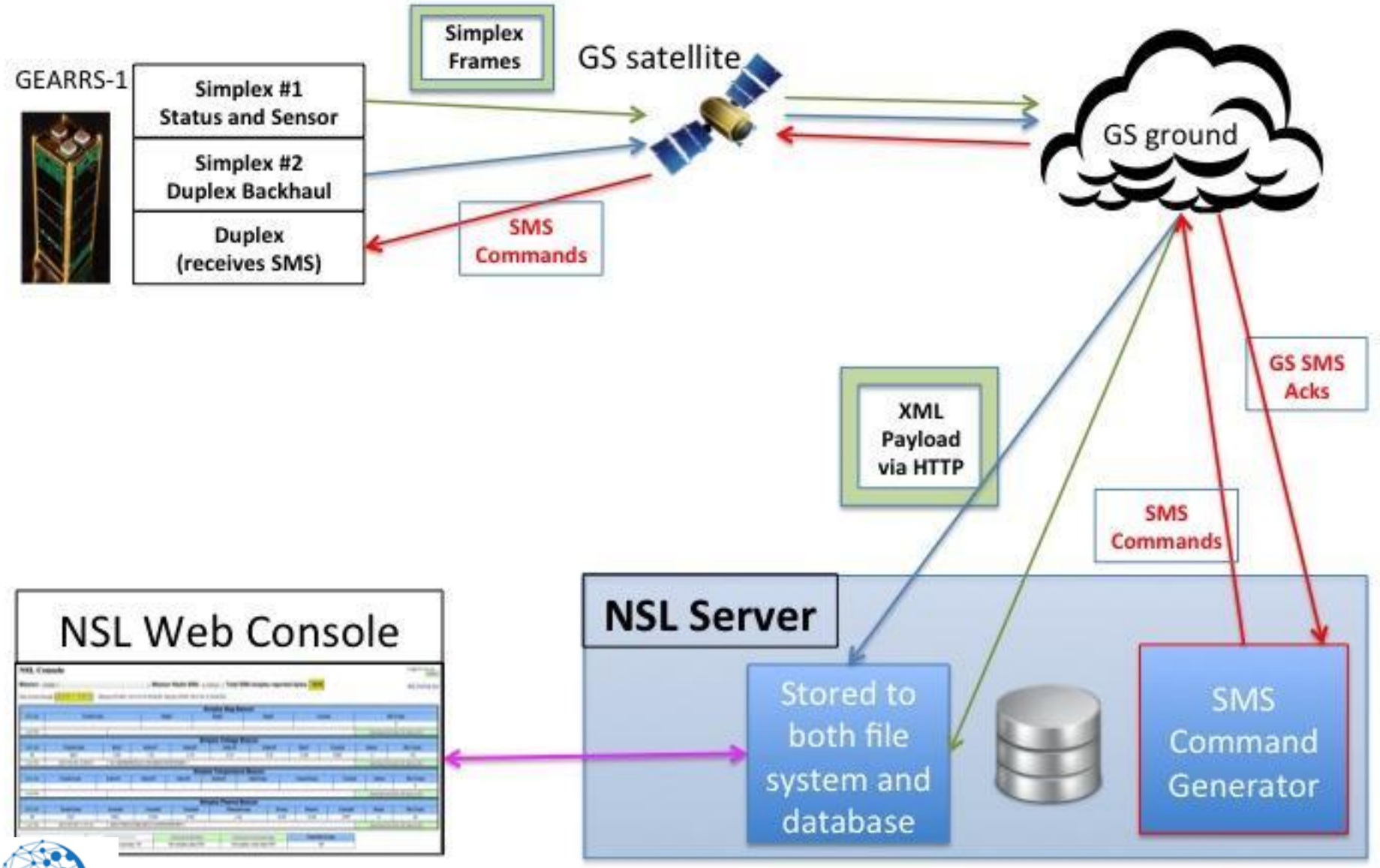
Eyestar Duplex

Duplex: 20 Mbytes/day, 700 Bytes/sec

2 way- Commanding, 20 MB/day, 50% Anywhere/Anytime data, pointing, ARM processor, Geolocation, Handshaking,

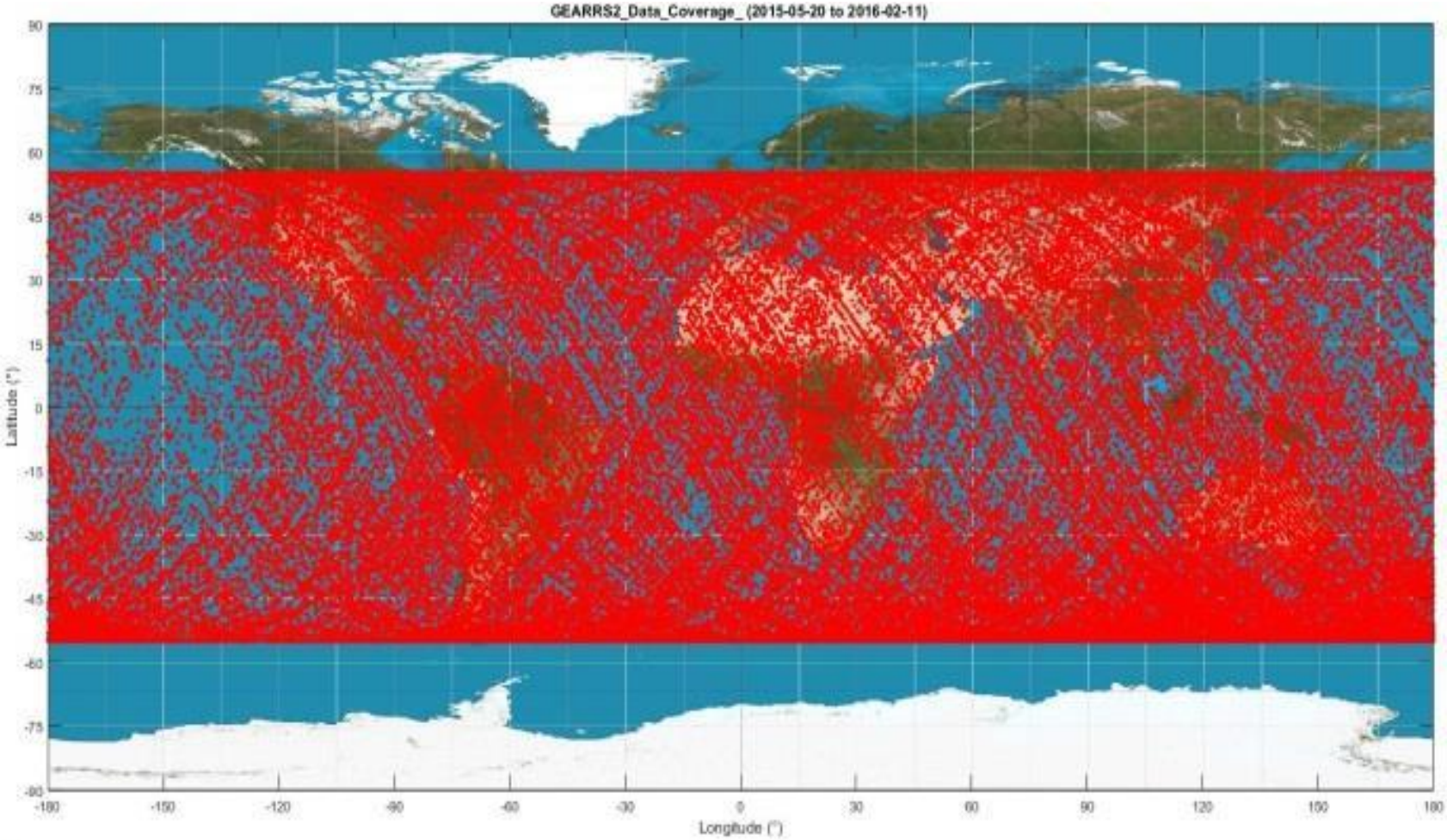
2 of 2 Validated in LEO Orbit!
3 week available NSL Stock

GEARRS-1 Data Link Model

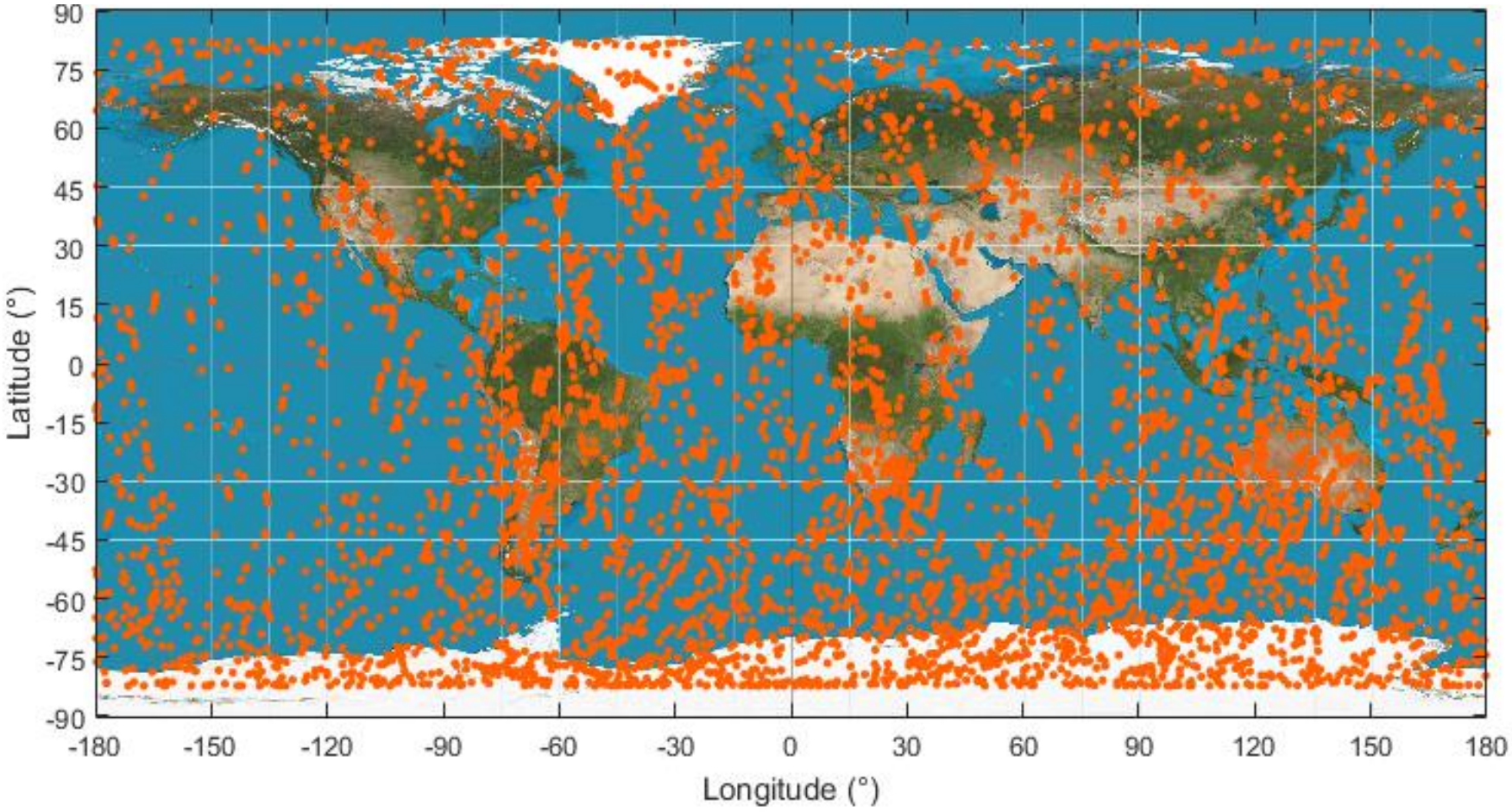


GEARRS2 Globalstar Coverage

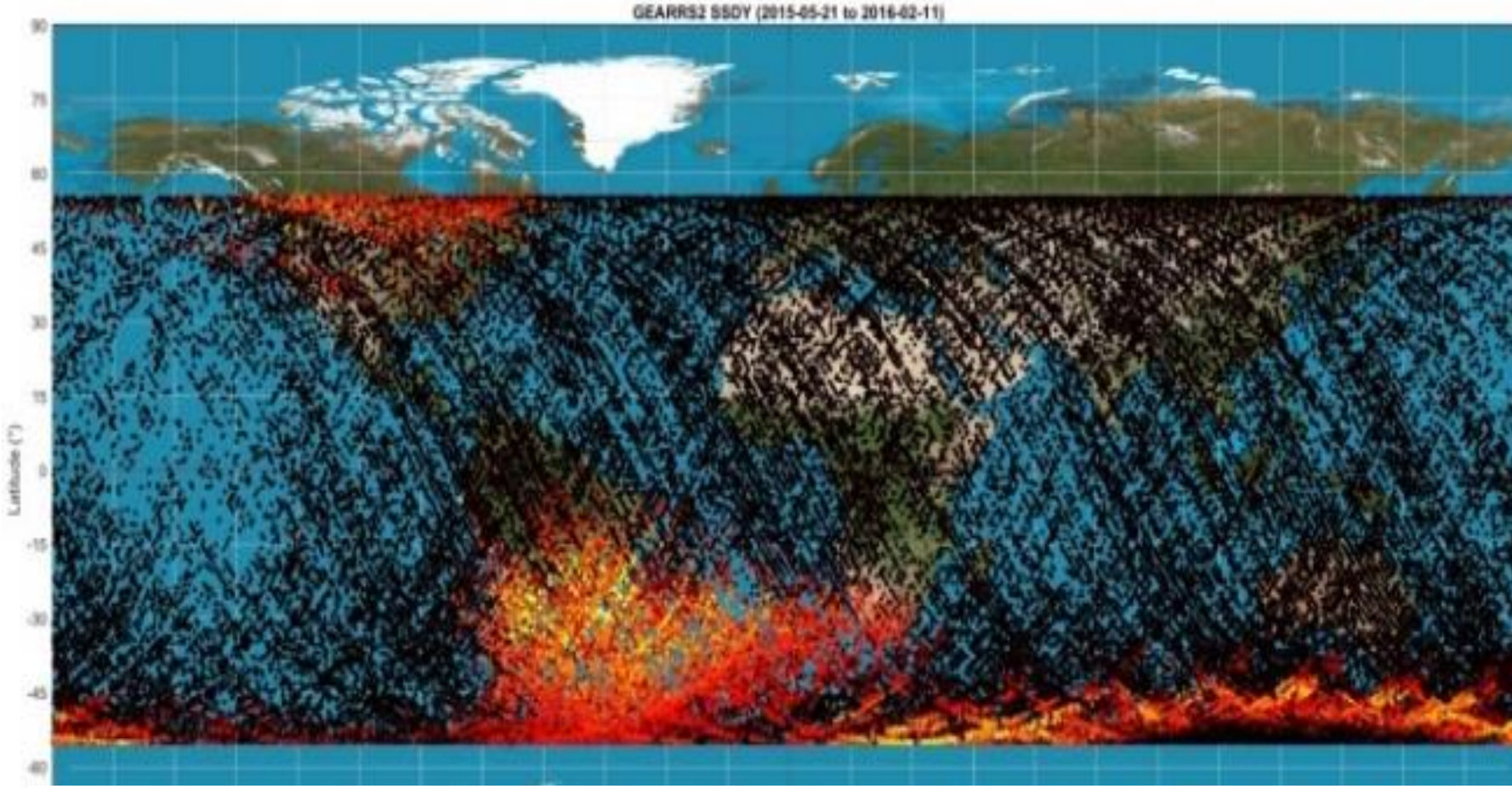
Some GEARRS2 Simplex raw data Raw Data Orbits before projection and sampling Normalization



EyeStar Link for Polar Orbits



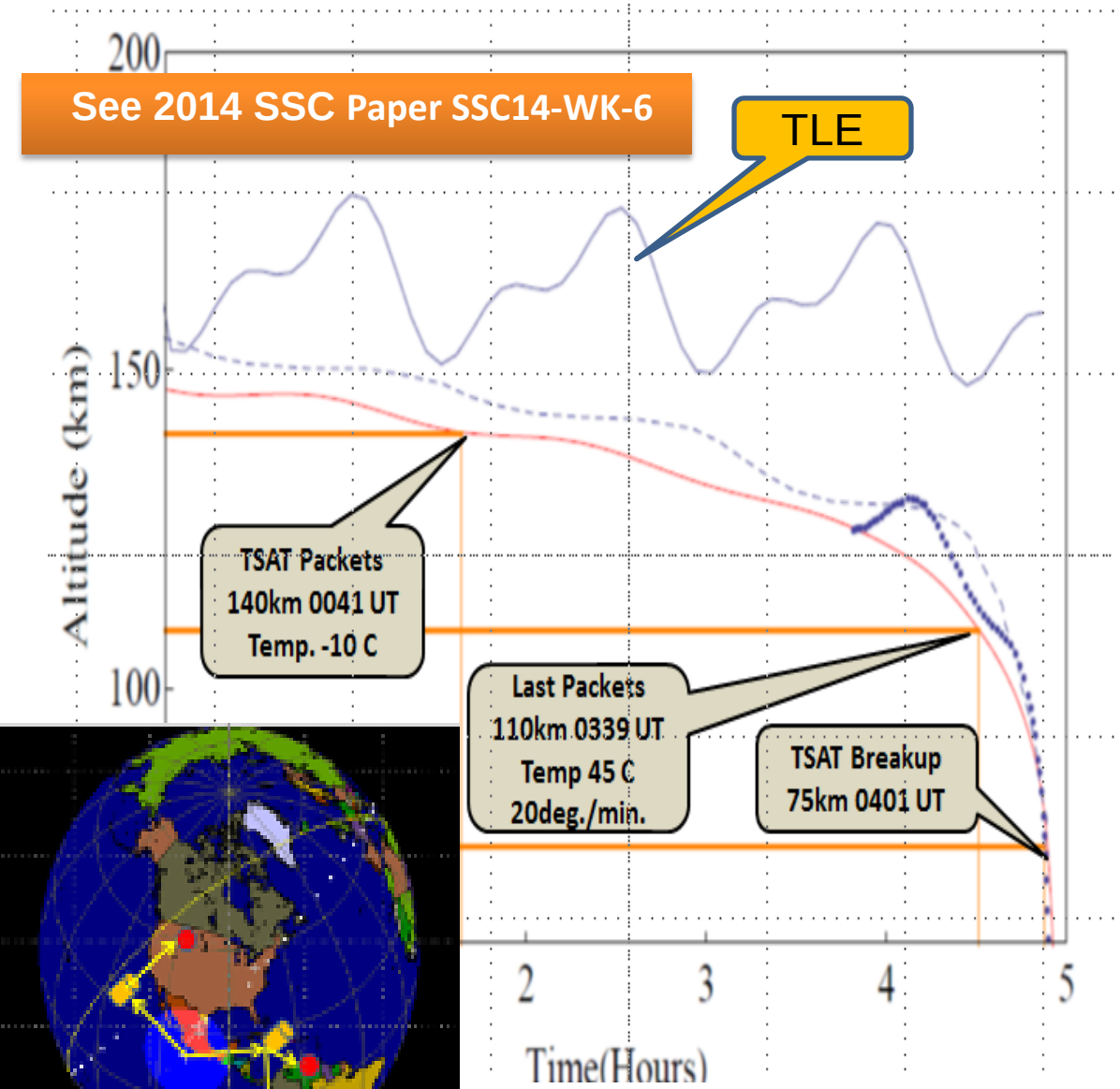
Recent Simplex data from a polar orbit satellite mission, from January 2019. Note the good transmission throughput over the poles. Globalstar works well over the poles for satellites and 30 km Balloons.



NSl-EyeStar Simplex energetic particle data from several orbits of GEARRS2. Small gaps in track show duty cycle of transmitter and long gaps due to sun sync of 78 packets of data sequenc to save system power. Note the South Atlantic Magnetic Anomaly (SAMA) and the Aurora Oval GEARRS Simplex coverage maps are very uniform over the entire earth with a weaker coverag area in the Pacific Ocean. The 53 deg. latitude cutoff is due to the GEARRS Sat. 53 degree inclination and not due to the Globalstar link limitations

TSAT 110 km Reentry Data (T=20deg/min)

See 2014 SSC Paper SSC14-WK-6



ELEO Electron Density

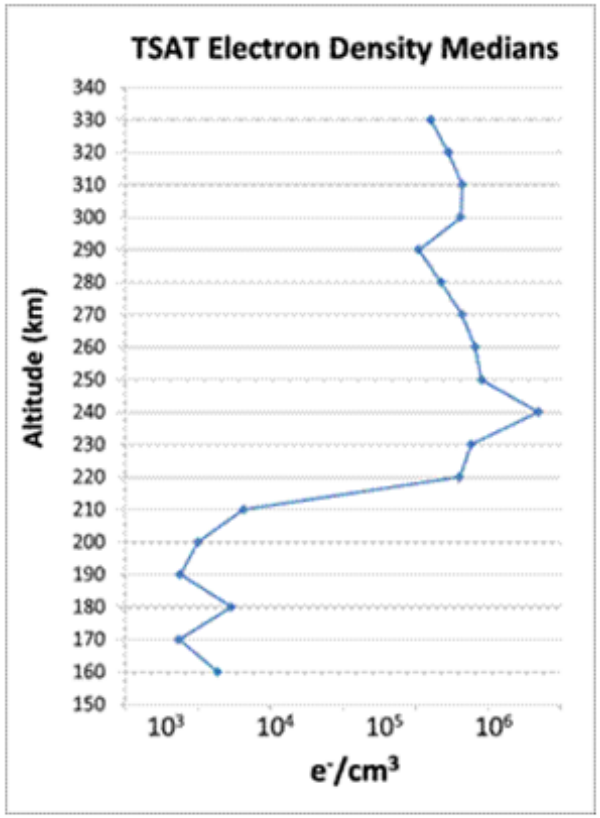
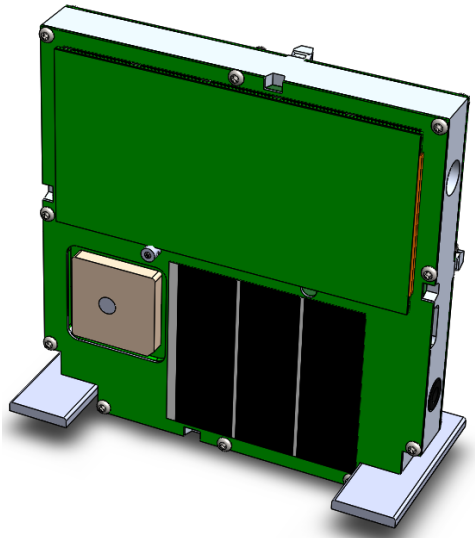
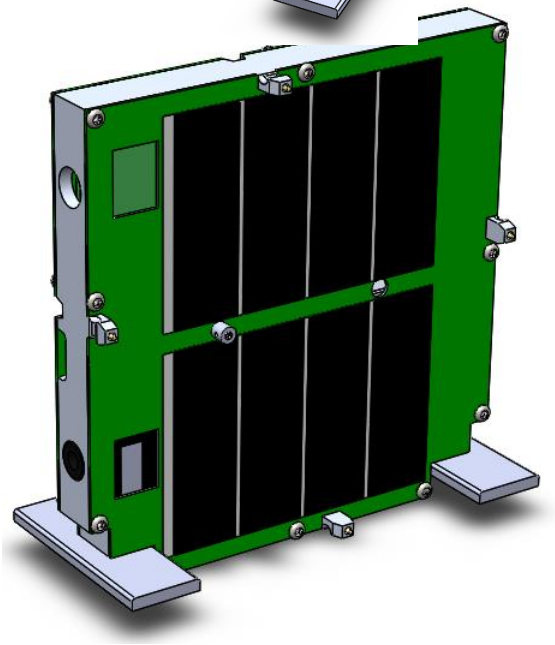


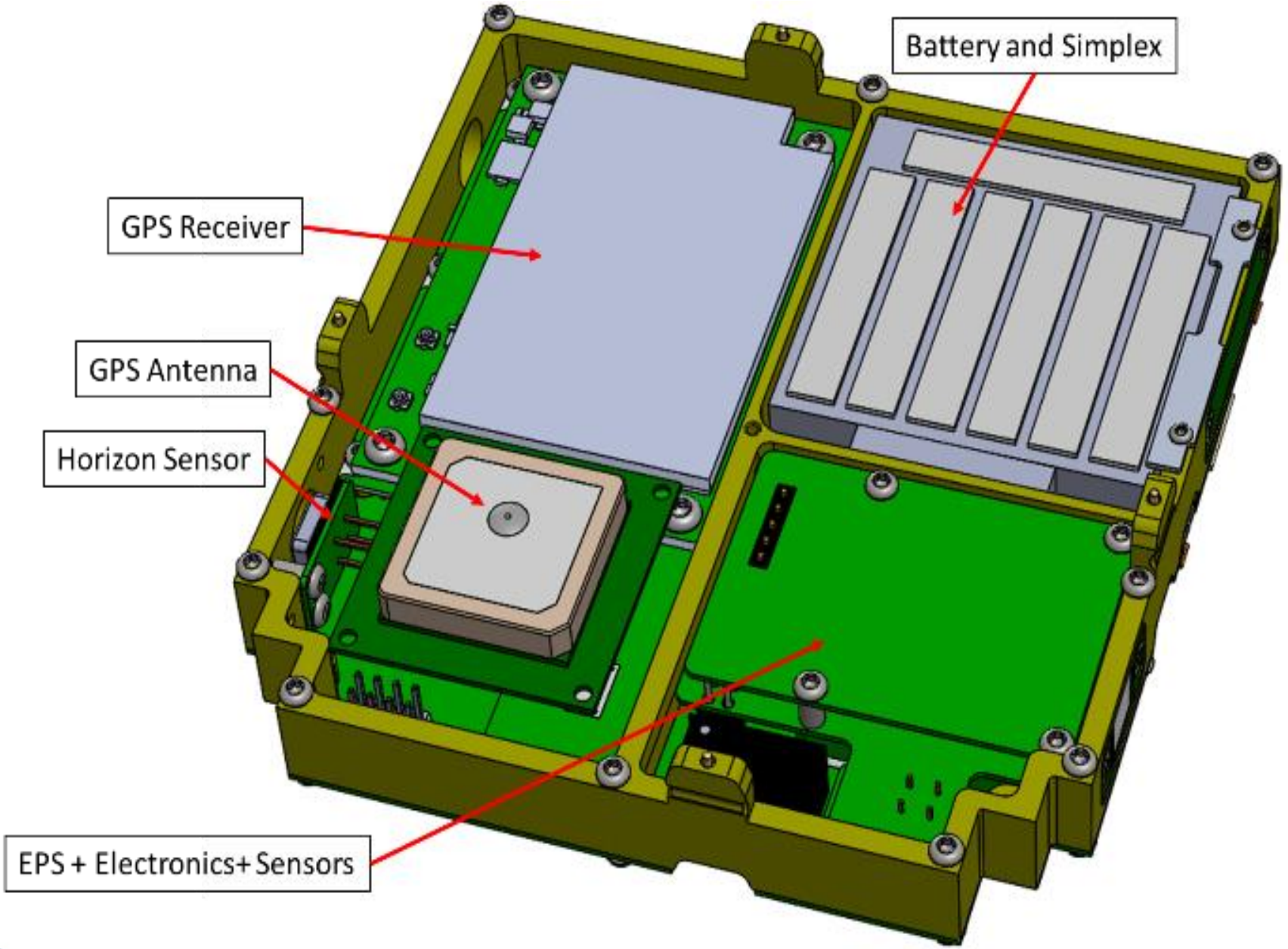
Figure 19: Mission medians of electron density for various orbit altitudes (10km bins). The higher density in the F-region transitions to the

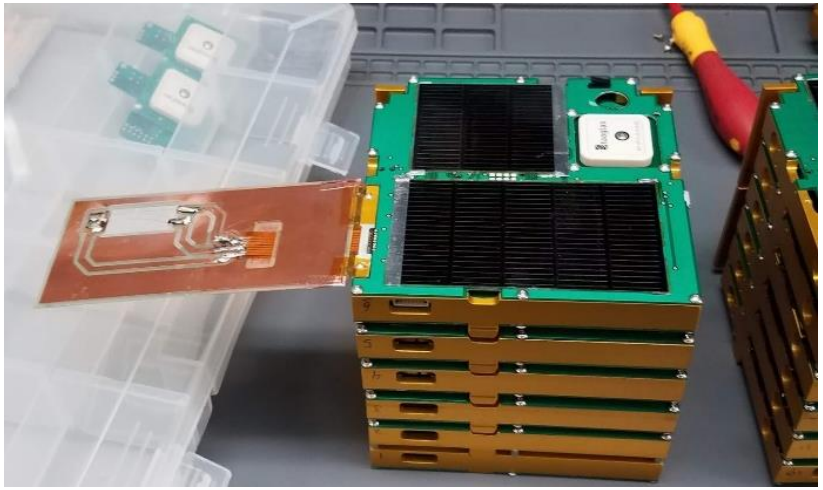
ThinSat Integration into CSDs



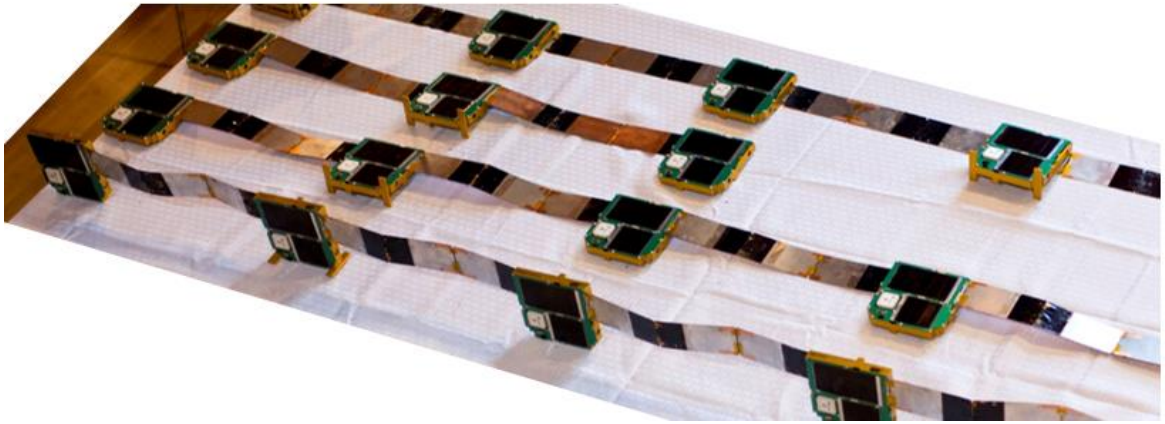


Above is a stack of 21 ThinSats which will be separated after being ejected from the CSD.


Battery and Simplex
GPS Receiver
GPS Antenna
Horizon Sensor
EPS + Electronics+ Sensors

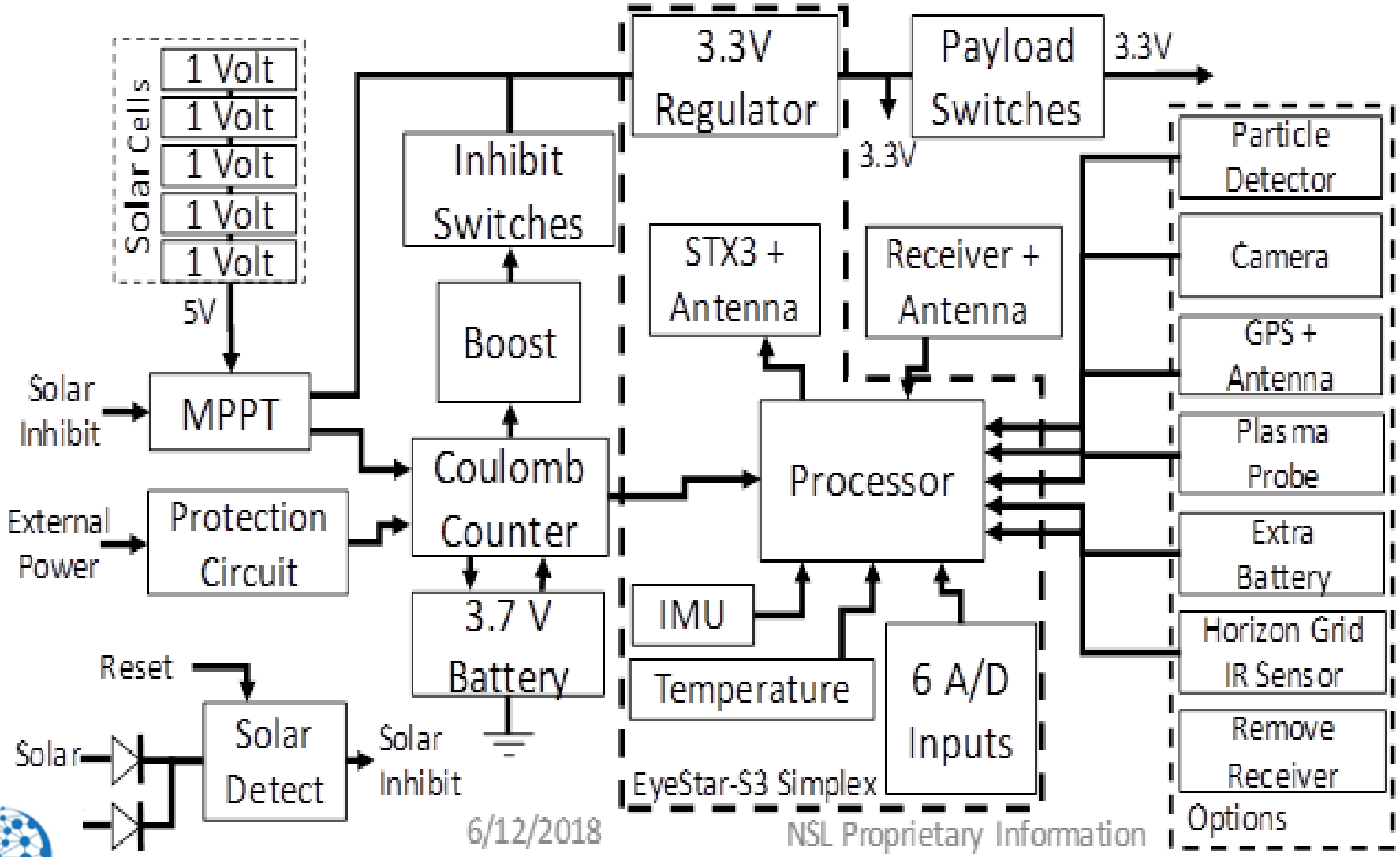


Example of small boom used for electron emission using a hot wire connected to the flex bus to transfer current along a magnetic field line.

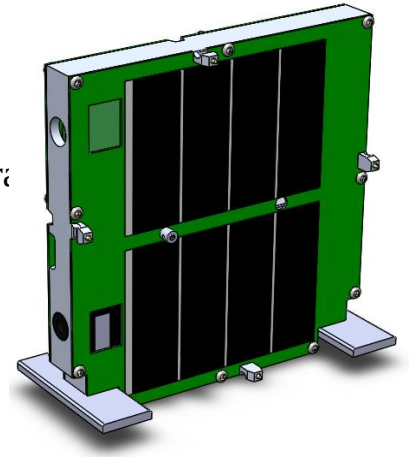


Strings are ideal architectures for data and power connection between individual ThinSats for coordinated experiments with different purposes such as 1) ThinSat with GPS, IMU, cameras, 2) Propulsion unit like a train and extra batteries (like coal car), 3) Space weather experiments plasma and particles, and 4) Space Weather experiment with B and E field deployables etc. The string with the flex cable bus can also act as a boom for plasma experiments. Can also get gravity gradient stabilization with longer strings and various flying angled and circular geometries.

ThinSat Block Diagram

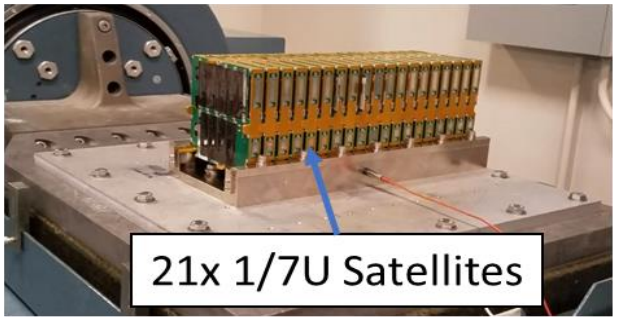


ThinSat: New Architecture & Features for Space Weather

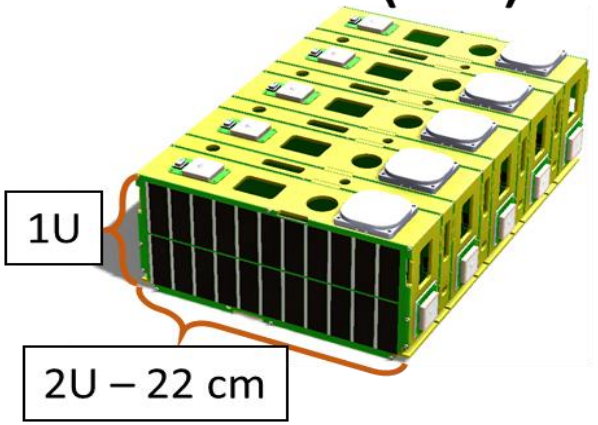


1) **Ease:** Automated Assembly using two exterior parallel PC Board composite Asm. structura Shielding for radiation and EMI reduction (Pancake assembly), Globalstar/NSL product fits with 24/7 real -time monitoring for ordered database of SW constants,
2) Larger **Solar Array Area and Fit**
3) **Aerodynamic** for less drag when small edge is pointing into ram direction,
4) **Radiation Shielding** of Atmosphere in VLEO orbits greatly reduces Radiation Damage **(Resilience)**
5) **Much lower cost** by a factor of 10 for constellations to manufacture compared to using many smaller PC boards with connectors. One Main PCB with few connectors
6) A ThinSat is like a **FlatSat** for easy testing and **debugging**,
7) Advanced Manufacture and **Robotic assembly** with modular ThinSat frames and 3D printing,
8) Ideal for **Constellations** since easy to mass produce and launch with existing Cubesat Launchers
9) Improved **Thermal** heat dissipation and isothermal shorting,
10) Great for **pushing New Technologies** to smaller smart phone sizes,
11) Can have much greater **Radar cross section** especially with the foldouts,
12) Ease of calibration, charging, Burn-in, and environmental **Testing**, and
13) Can separate noisy Bus and payload sections with a foldout: I**solation** of sensitive low power plasma, magnetic, and cooled experiments.
14) Others… Problem: Volume limited but can go to multiple T sections or Scale to larger ThinSats

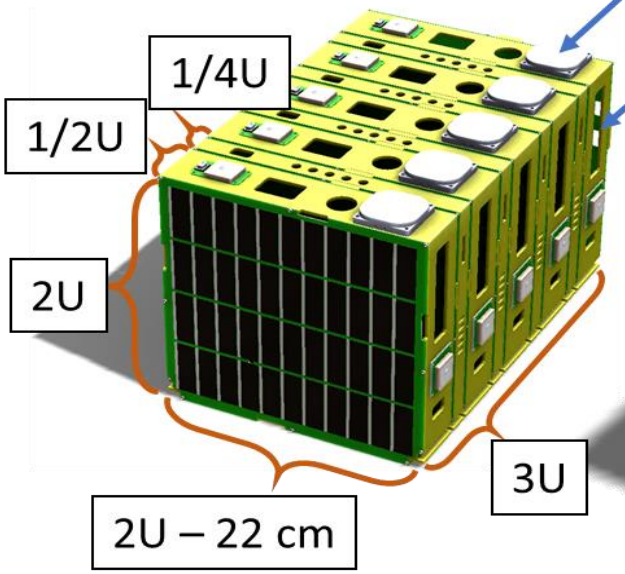
1x3U (3U)



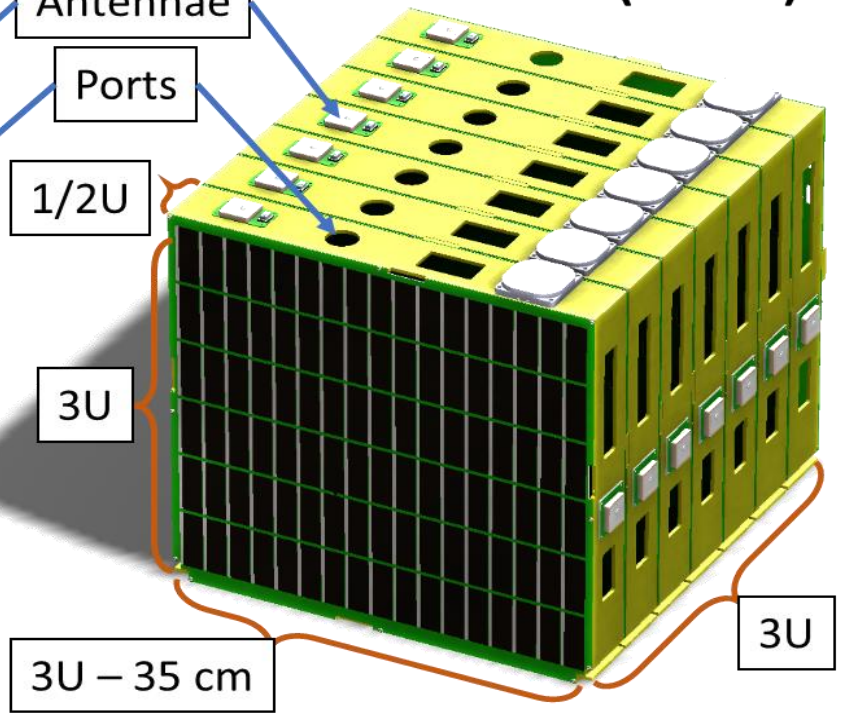
2x3U (6U)



2x2x3U (12U)



3x3x3U (27U)



Existing Educational Launches

- NG11 60 ThinSats, Launch April 17, 2019 with TSL and VS
- NG13 84 ThinSats, Launch April, 2020 with TSL and VS
- NG14 84 ThinSats, Launch October, 2020 with TSL and VS

Research and Operational Next Steps?

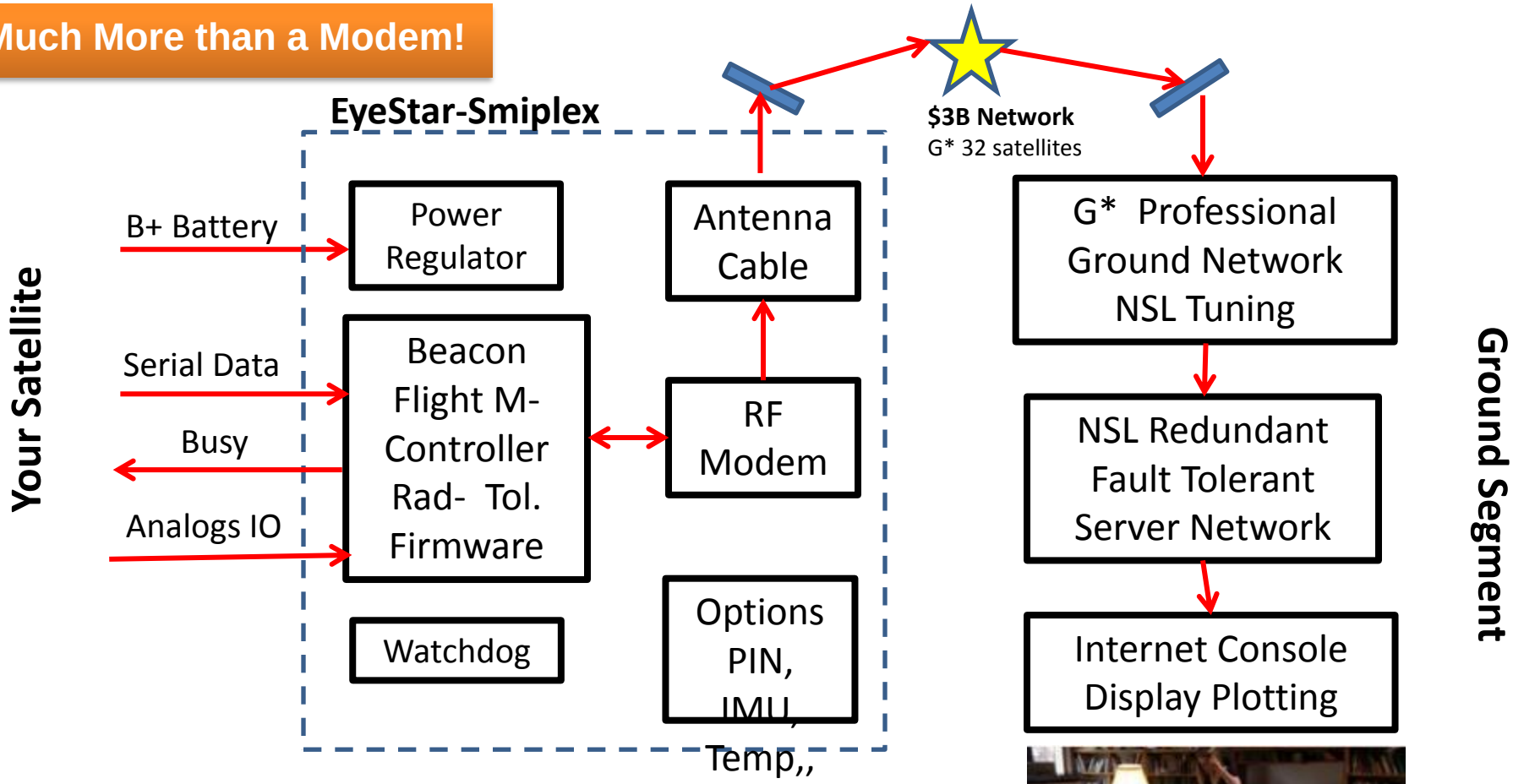
- 2019: Submitted SBIR for Space Weather Demo
- Please provide Feedback on ThinSat Constellations for Space Weather
- **Other AO Opportunities** with NSF, DOD, NOAA, NASA, and other interested Space Weather agencies, Departments, or Executive offices
  - Suggest a Space Weather Demonstration Array of 21 ThinSats in a 3-U Deployed from ISS or lower orbit launches. (Estimate about $1M with delivery in 1 Year)
  - Dream would be to launch a constellation every 6 months with the ThinSats having various drag coefficients that cause reentry every several days.
  - Advise us of other teaming opportunities
  - Small sensor Suggestions for SW?
  - Available at this conference for discussions: Hank Voss, Matt Craft, Matt Voss

Experience: 15 CubeSats launched and many ready for launch (80) using the Globalstar constellation of satellites for communication,

1. Low cost EyeStar Link: *Anywhere-Anytime, 24 hr./7days/week coverage*
2. *Critical Piece for Mission Success (9 to 700 Bytes/sec but practically 24/7)*
3. *No Ground Station required .. Ground Segment Included with Radio cost*
4. *Globalstar Capacity for TT&C for 1000's of satellites*
5. *Fully Operational NSL ground segment data and display (over 2 years)*
6. *Agile 1-3 month Delivery GEARRS2 and GEARRS1* (NSL precision unit body all-in-one FastBus Series)
7. Globalstar link below 200 km from reentry to many earth Radii!?

NSl Simplex Products (STX-3 and STX-2) Research Grade, Commercial License, TRL=9

Much More than a Modem!



PCB, Shielding, Layout, EMI Test, Globalstar/NSL Value Added Reseller (VAR) Product, ICD, Engineering Model (EM), Firmware Options, Quality Assurance, Burn-in, Certification, Flight Model (FM), FCC License, NSL Support